Pacific Gas and Electric Company
Long Term Procurement Plan Proceeding

Renewable Integration Model and Methodology

August 24-25, 2010 Workshop

Agenda

10:30 am	Renewable Integration Model Methodology
11:30 am	Q&A on RIM Methodology and Key Assumptions
1:00 pm	Presentation of Assumptions, Preliminary Results, and Model Demonstration
2:30 pm	Q&A on Assumptions, Preliminary Results, and Demonstration

The Brattle Group

PG&E

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Renewable Integration Model Presentation
LTPP Workshop

Presented by:
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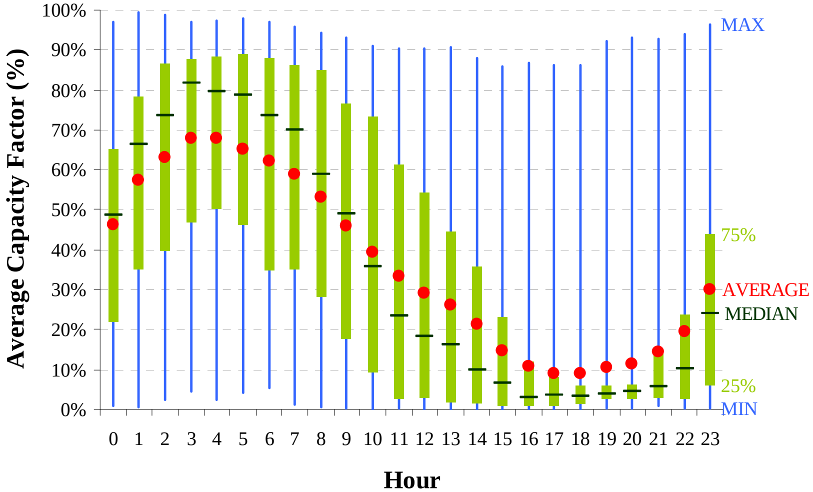
August 25, 2010

Contents

Renewable Generation Characteristics

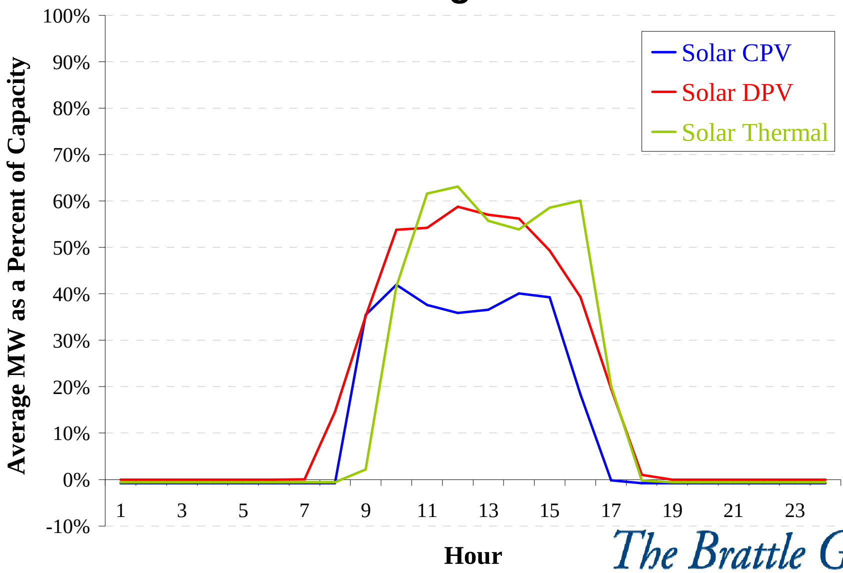
- Renewable energy provides significant environmental benefits
- Incorporating them into existing system consists of new challenges
- Some renewable resources have variable output; wind and solar with the following characteristics:
  - **Variability:** the magnitude of power output from one moment to the next can change dramatically
  - **Unpredictability:** sudden changes in generation output not well-forecasted

Sample Wind Profile for July
Western Region of U.S.



Source: Calculated based on hourly wind generation data from TEPPC.

Sample Solar Profile for January
Western Region of U.S.



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Motivation and Goals of the Renewable Integration Model (RIM)

PG&E's Goal: Analyze and estimate resource requirements and costs associated with integrating various levels of variable generation resources

Various other wind integration analyses revealed that:

- ♦ Statistical processing to parameterize intra-hour volatilities is needed
  - Lack of granular historical data requires using assumptions to forecast future renewable energy production patterns
  - These intra-hour volatility assumptions drive results
- ♦ Many rely on production cost modeling to simulate full systems
  - Production cost simulations are not designed for intra-hour analyses
  - Difficult to determine if models represent actual operations and the use of reserves
- ♦ Most analyses ignore potential incremental capital costs associated with incremental resource additions

A simple, transparent and flexible model is needed

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Important Considerations for Model Design

The Renewable Integration Model (RIM) focuses on the central issues:

- Evaluate incremental service requirements
- Estimate magnitude of resources to provide those services
- Estimate variable and fixed costs

RIM is designed to achieve above goals with functional features below:

- Simple but careful
  - Uses simplifying assumptions to represent complex issues
  - Focus and care is placed on using all available information to best simulate reality
  - Runs quickly
- Transparent
  - Accepts user input assumptions
  - Uses fully transparent calculations
- Flexible
  - Can provide results across many scenarios and resource portfolios
  - User defines the analytical period and the system conditions
  - Can be updated as system and forecast capabilities change
  - Portable – based on Excel spreadsheets

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RIM Overall Structure

Data Input	Calculations	Output
Installed variable generation	Estimate incremental operational requirements	Flexible requirements (regulation, load-following, day-ahead commitment)
Detailed load & generation profiles	Estimate system's reliability requirements	New capacity required to integrate variable generation
Forecast errors for load & generation	Quantify resource requirements	Mix of resources based cost assumptions
Costs of conventional generation	Estimate fixed and variable costs of integration	Fixed and variable costs of integration

RIM Key Assumptions

Like all models, input assumptions drive model results.

RIM has relatively few parameters:

- **Load**
  - Parameters that describe load forecast errors and load variability (can be derived from historical data)
  - Load growth
  - Alternatively, a future year load profile can be used
- **Wind and solar**
  - Parameters that describe forecast errors and output variability (can be derived from historical data)
  - Correlation coefficients for generation output across sites
- **Resource costs and characteristics**
  - Capital costs
  - Heat rates
  - Fuel costs
  - Emissions costs

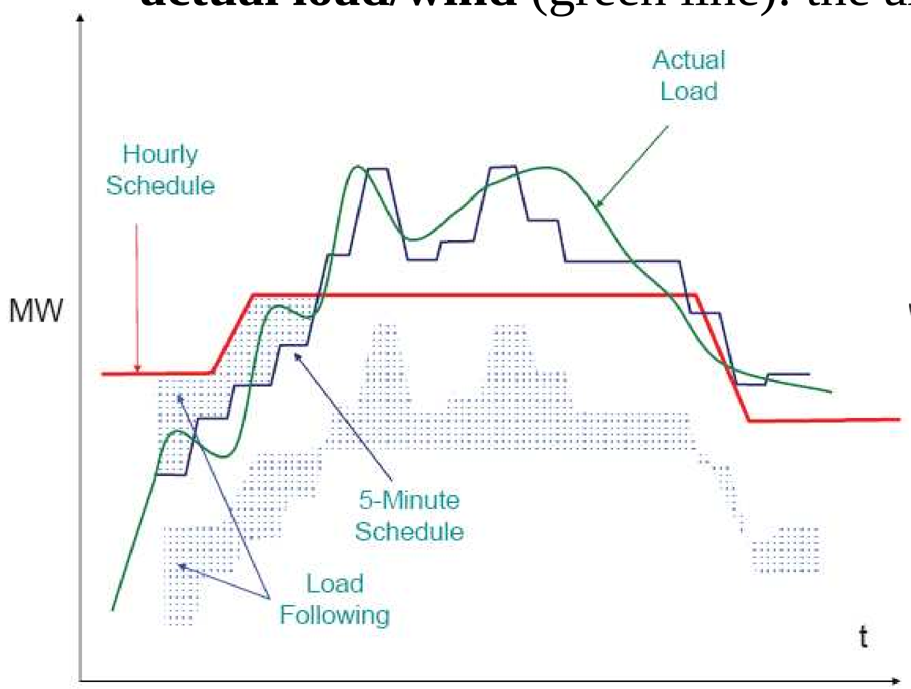
All default parameters can be updated and changed by users

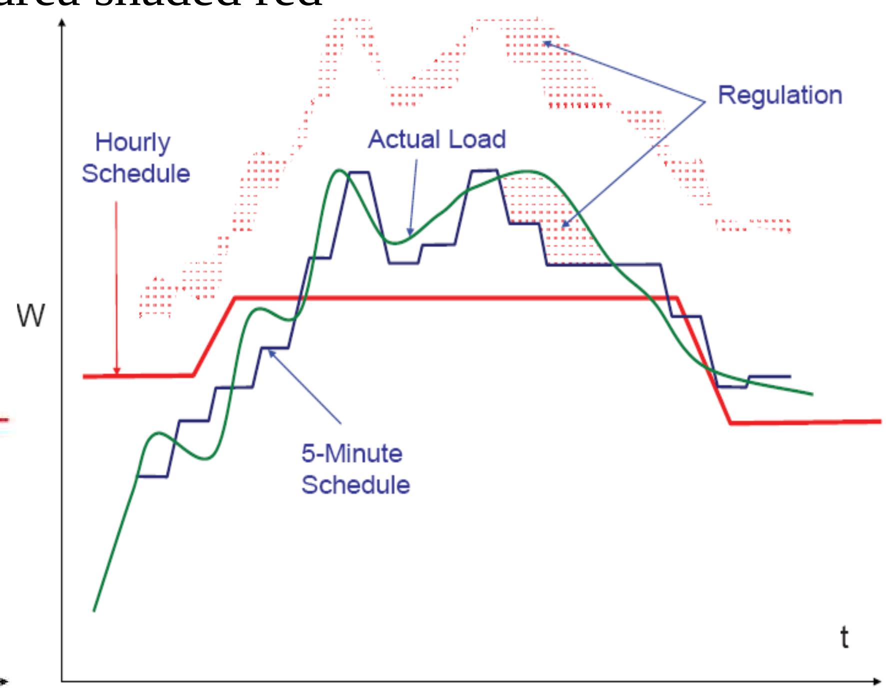
Contents

RIM uses CAISO's definition regulation and load following

The CAISO differentiates the two services by the scheduling process and the timing of the forecast

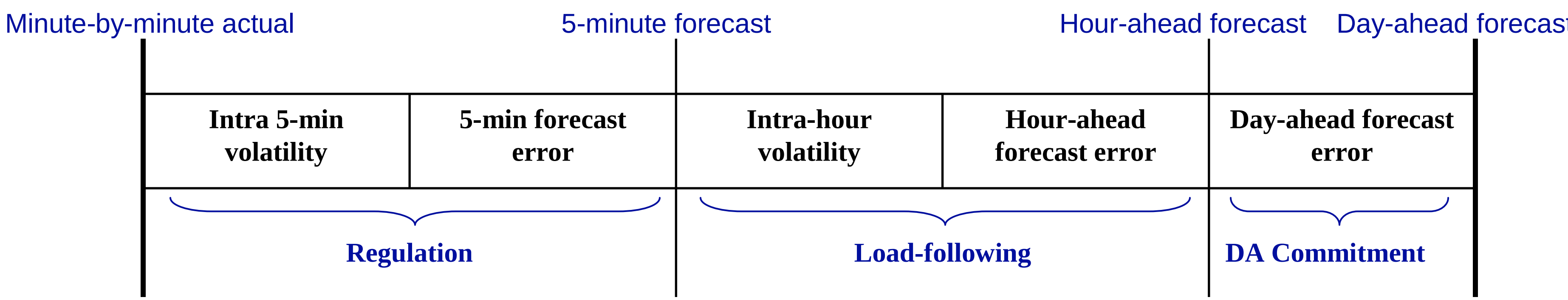
- Load following = difference between the **hourly schedule** (shown as red line) and the **5-minute schedule** (blue line) of generation to meet forecast load: the area shaded light blue
- Regulation = difference between the **5-minute schedule** (blue line) and the **actual load/wind** (green line): the area shaded red





Source: CAISO Integration of Renewable Resource, November 2007

Types of Services Needed to Compensate for Variability and Unpredictability



Regulation

- RIM uses parameters that describe deviations from relevant scheduling
- Two primary parameters: intra 5-min volatility and average 5-minute forecast error (next slide explains)

Load following

- RIM uses parameter that describe deviations between the 5-minute and the hour-ahead schedules
- Two primary parameters: intra-hour volatility and average hour-ahead forecast error

Day-ahead commitment

- Deviation between day-ahead and hour-ahead schedule

The model uses all 5 statistical parameters shown in diagram

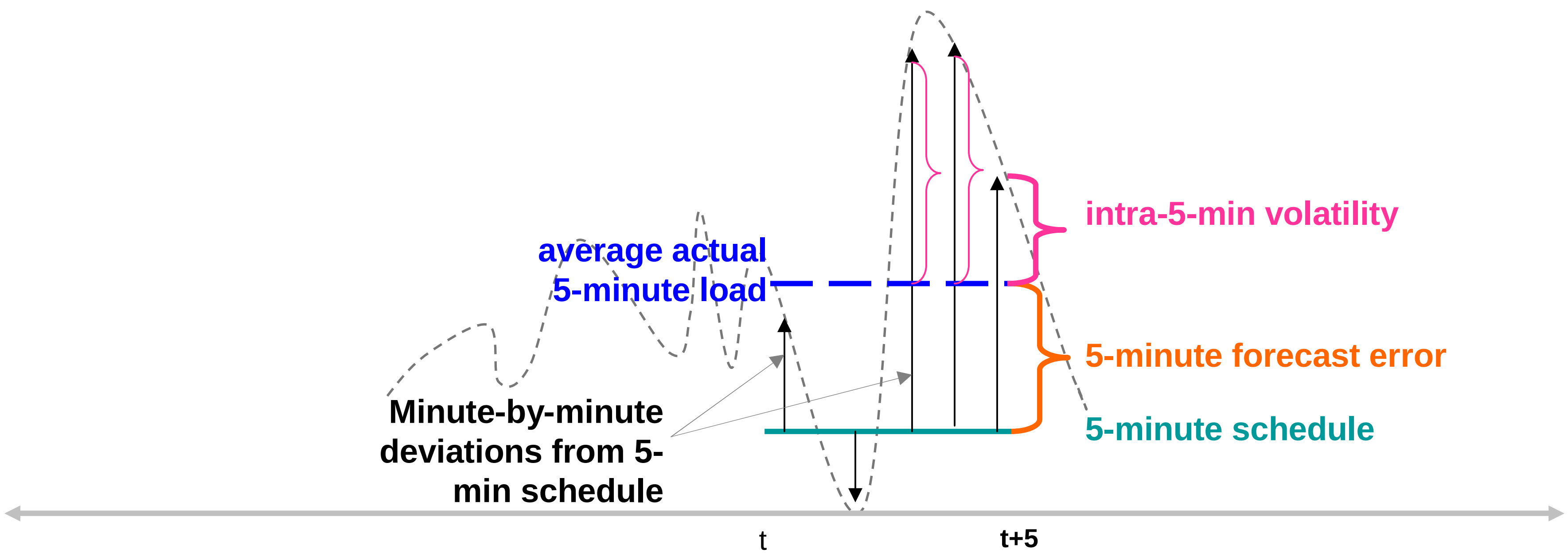
RIM uses statistical relationships of schedules and actuals to estimate services requirements

Regulation requirement for each 5 minute interval is estimated with two components of variance of load and generation:

1. *5-minute forecast error,* PLUS
2. *intra-5-minute volatility*

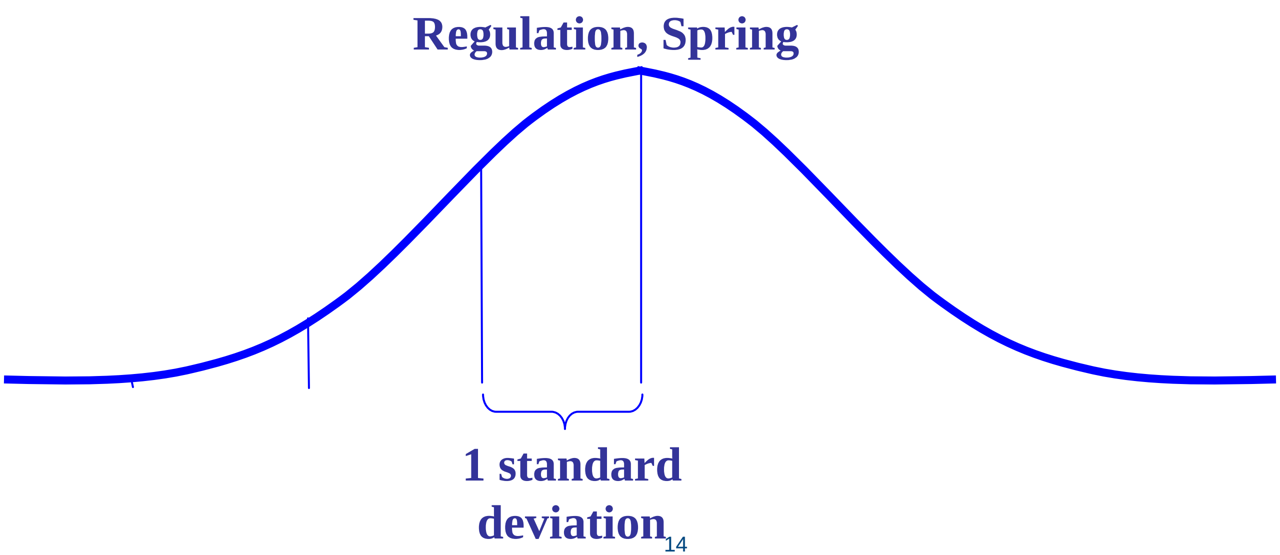
Analogous estimation methodology is applied to load-following

Day-ahead commitment need uses forecast error only



RIM summarizes regulation, load-following and day-ahead commitment needs by season

- RIM uses the standard deviations to estimate the services needs
  - User can input the magnitude and the number of standard deviation used to determine the needs
- RIM takes into account the correlation between sites and forecast errors
  - All of which are parameterized and user-driven
- RIM reports the operational requirements for regulation, load following and day-ahead commitment for each season



Derivation of Resources Required for Integration

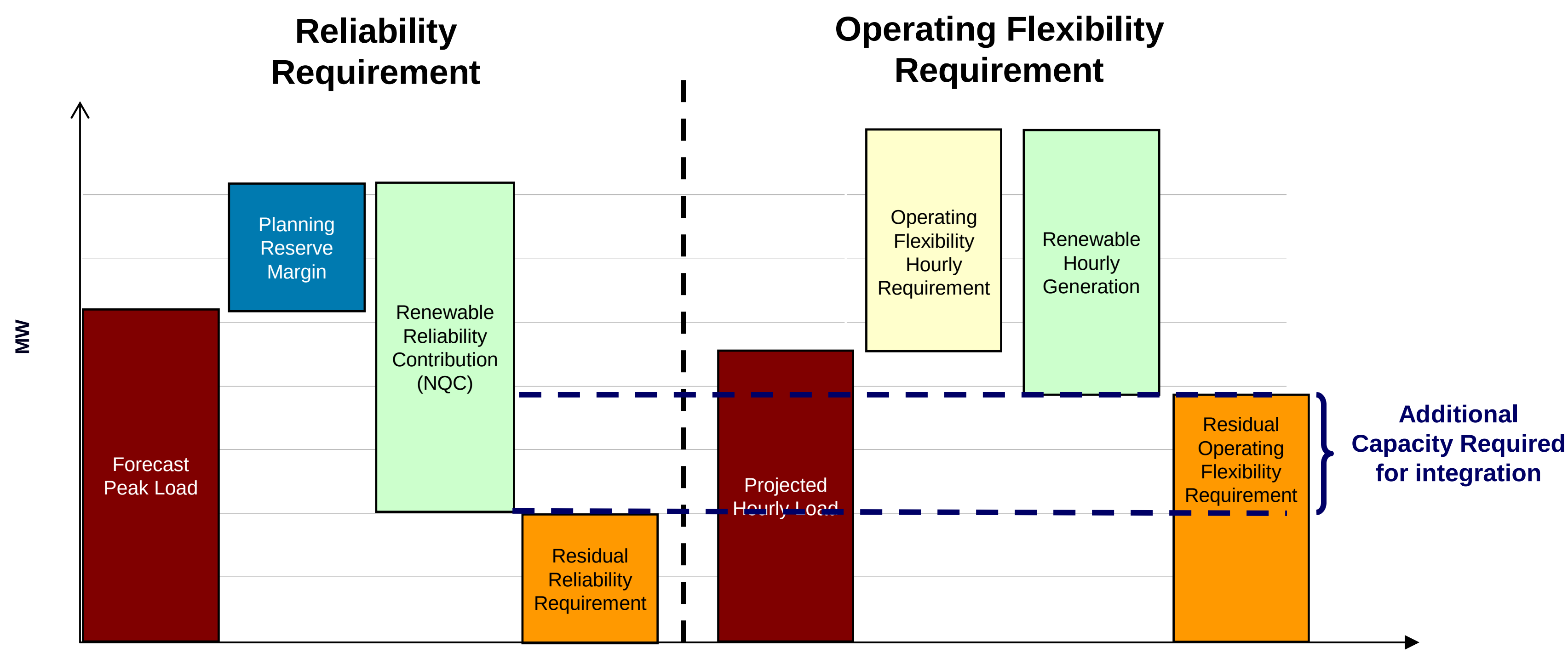
Assumptions:

- New or existing generating capacities can be used to provide the operational requirements of the system

Steps Taken:

- Estimate the magnitude of resources needed to meet the operational flexibility requirement after renewable resources are added to the system
- Estimate the resources needed to meet the reliability requirement of the system
  - Load plus planning reserves
- Compare the two and determine if additional resources will be needed above the planning reserve requirements

Steps in Estimating Resource Requirements



Forecast Peak Load
\+ Planning Reserve Margin
– Reliability Contribution of Renewables (NQC)

Reliability Requirement

Hourly Load
\+ Hourly Operating Flexibility Services
– <u>Hourly renewable generation</u>

Operating Flexibility Requirement

Contents

Estimation of Fixed Costs

RIM uses 3 categories of inputs assumptions to derive the fixed cost of integration

- Fixed and variable costs of resources used for integration (*e.g.* CCs, CTs, storage, other technologies)
- The planning reserve requirement
- *Composite* load duration curve (*e.g.* load net of renewable generation, *plus* hourly operational requirements for integration).

Estimation of Variable Costs

RIM uses simplifying assumptions about operations to estimate variable costs:

- The cost of potential daily startups from resources to provide the needed services
- The cost of potential out-of-merit dispatch during ramp up and down time
  - Simulated with efficiency differential between in-merit and out-of-merit resources
  - This approach assumes the system potentially will need incremental resources to meet faster ramping during ramp up and down hours
- For meeting regulation needs, RIM can incorporate an efficiency penalty for all hours a resource must operate at a less than fully efficient set point

Observations from Other Recent Integration Analyses

Compared to production cost simulations, RIM's variable cost estimation uses consistent methodology

- ♦ Regulation and load following are translated into regulation and other reserves such that certain resources are "held aside" to react if necessary
- ♦ When certain resources are held aside, the next resource must be used – either by demanding certain resources to be "on reserve", or putting the in-merit resource on reserve and move up the dispatch curve to serve energy
- ♦ Some out-of-merit dispatch occurs – RIM simulate with using efficiency "penalty" between in-merit resource and the "next one up" on the dispatch ladder
- ♦ This is consistent with system operations
- ♦ All production efficiency assumptions can be adjusted by users

Contents

Primary Strengths of RIM

- Full transparency
- User control over key assumptions
- Clear & flexible cost methodologies
- Ease of updating parameters as better information is available
- Ease of adaptation to forecast improvements
- Accommodates up to four renewable generation categories
- Facilitates policy discussions
- Based on CAISO-equivalent service definitions

Contents

RIM Applications

RIM can be utilized to:

- Quantify incremental effects of changes in generation portfolio
- Estimate potential cost savings associated improved generation forecast and/or operational processes
- Evaluate the potential effects of resource diversity among renewable generators
- Compare resource requirements and integration cost estimates across a *range* of potential renewable portfolio selections with fast model execution of scenario outcomes
- Evaluate the benefits/costs of alternative renewable portfolios prior to contracting

Questions and Answers

Pacific Gas and Electric Company
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Renewable Integration Model

Results and Model Demonstration

August 24-25, 2010 Workshop

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Outline

- RIM Objectives
- Review RIM Methodology/Inputs
- Preliminary Results
- Model Demonstration
- Closing Thoughts

RIM objectives

- Understand and quantify the integration requirements and cost of higher levels of intermittent resources
- Study impacts under different scenarios quickly
- Transparent, user friendly model

Outline

- RIM Objectives
- **Review RIM Methodology/Inputs**
- Preliminary Results
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- Closing Thoughts

RIM uses a variety of inputs to determine renewable integration requirements and costs

Inputs

- Installed intermittent renewable generation
- Detailed profiles and variability for load & generation
- Forecast errors for load & generation
- Cost of conventional resources

Model

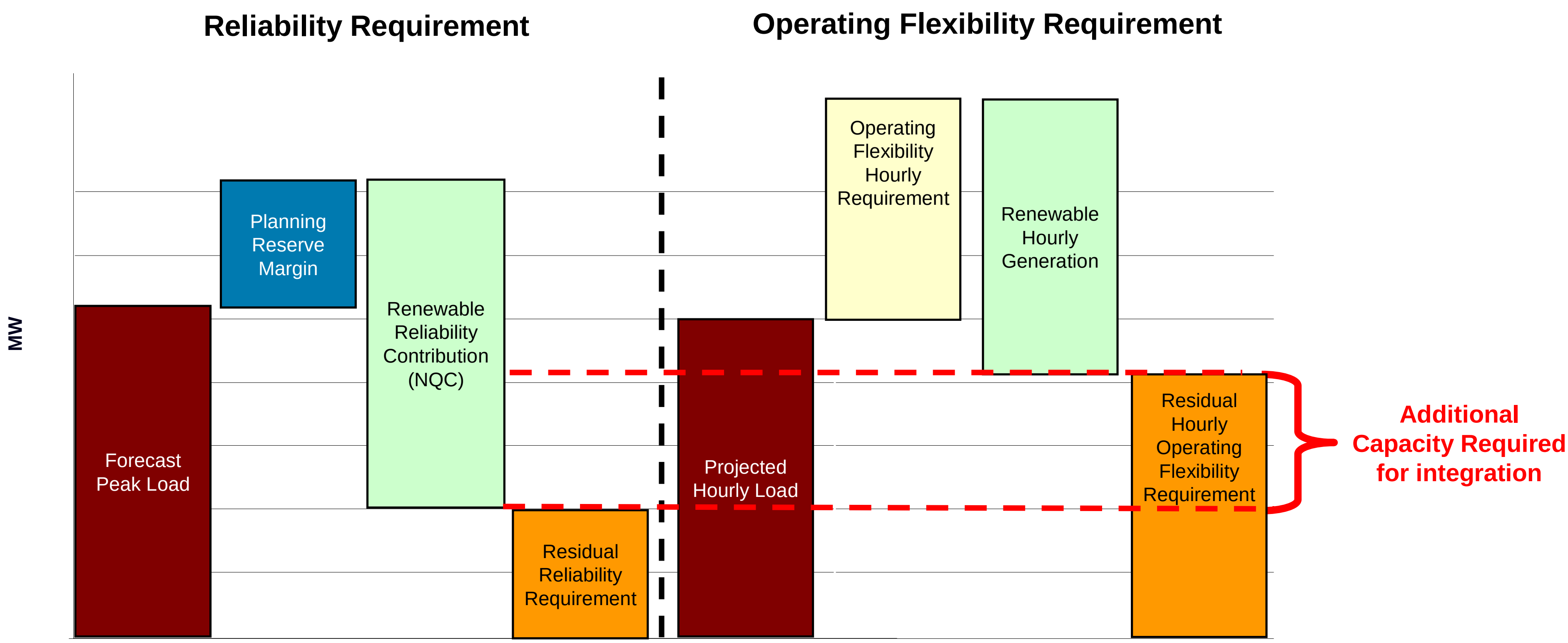
Renewable Integration Model (RIM)

Outputs

- Operating Flexibility Requirements (Reg, Load Following, Day-Ahead, Ramp)
- Resources required to integrate Intermittent renewables
- Fixed and variable cost of integration

To the extent possible, RIM uses the same inputs as CAISO's study

Additional capacity is required for integration if operating requirement exceeds reliability requirement



Forecast Peak Load
\+ Planning Reserve Margin
– Reliability Contribution of Renewables (NQC)

Reliability Requirement

Hourly Load
\+ Hourly Operating Flexibility Services
– Hourly renewable generation

Operating Flexibility Requirement

RIM's current inputs

RIM inputs can be modified by user

Load Inputs

- **Load forecast**: CEC's adopted 2009 IEPR forecast
- **Load profile**: 2005 load profile scaled to state-wide 2020 levels
- **Load forecast errors and variability parameters**: From historic experience, scaled to 2020 based on projected load growth*

Resource Inputs

- **Installed wind/solar amounts**: from CAISO's integration study
- **Existing wind/solar profiles**: from 2005 generation
- **New wind/solar profiles**: NREL 2005 simulated profiles
- **Wind/solar July capacity value (NQCs)**: from CAISO's integration study based on 2005 generation using adopted CPUC counting rules
- **Wind forecast error and variability parameters**: From historic experience*
- **Solar forecast error and variability parameters**: based on clearness index (5-minute error and variability), and persistence approach hour-ahead and day-ahead errors*

Other Inputs

- **Planning Reserve Margin (PRM)**: 15%
- **Forward gas prices** ~ $8.45/mmbtu in 2020 (nominal)
- **CT net fixed cost** ~ $160/kW-yr in 2020 (nominal)

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* See appendix for a comparison of current errors used by RIM with CAISO's Step 1 errors.

Outline

- RIM Objectives
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- **Preliminary Results**
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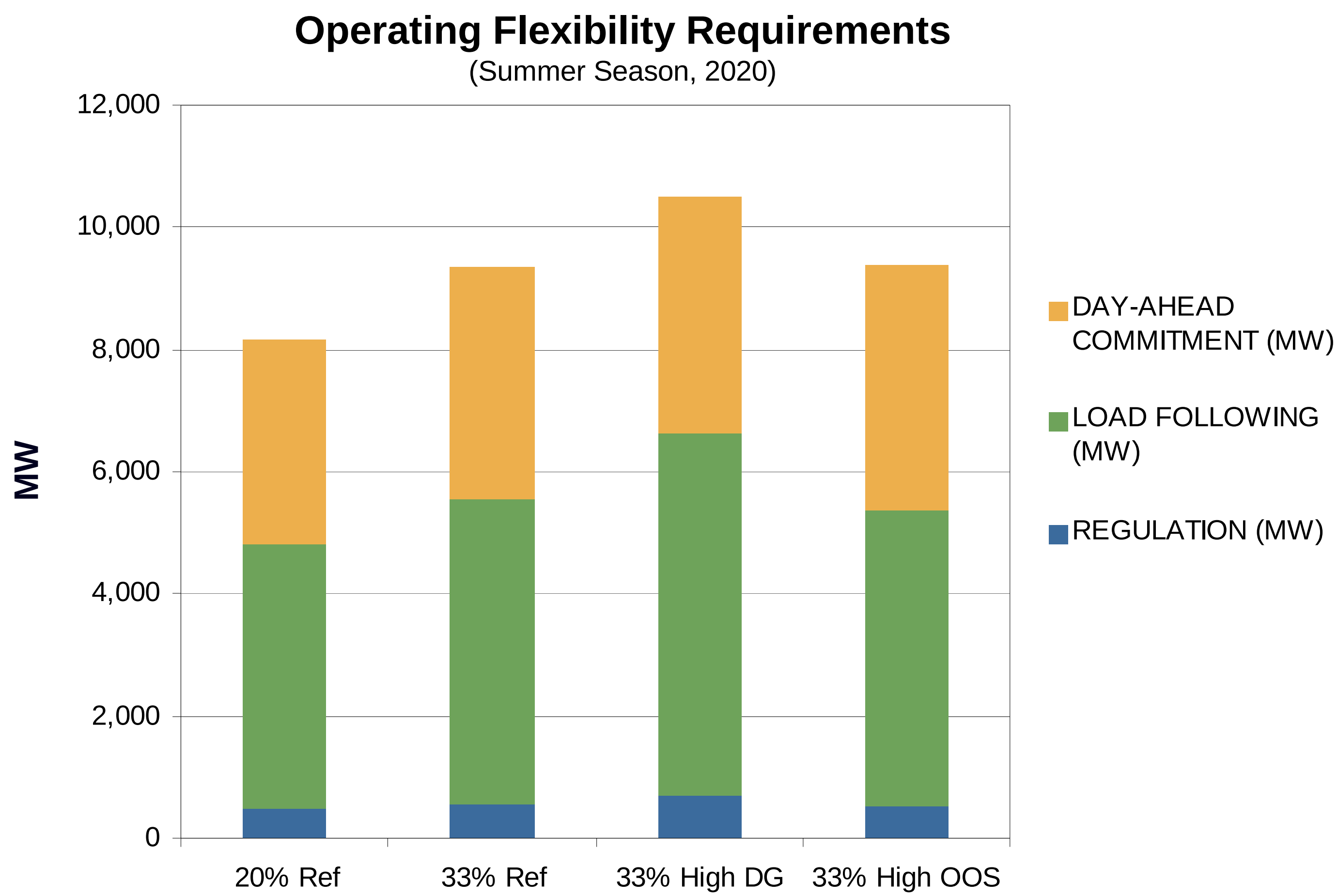
Operating flexibility requirements



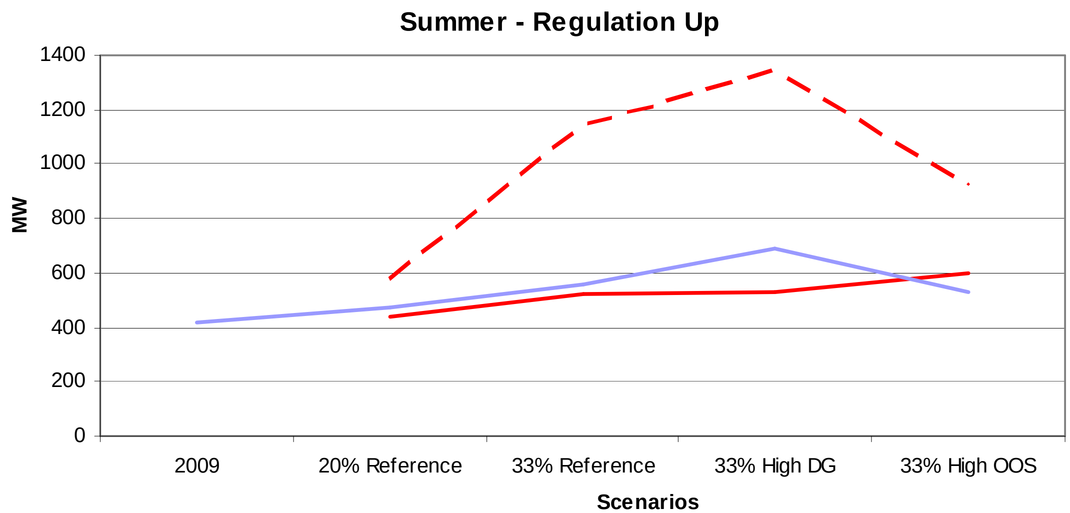
Appendix
Operating flexibility requirements by scenario

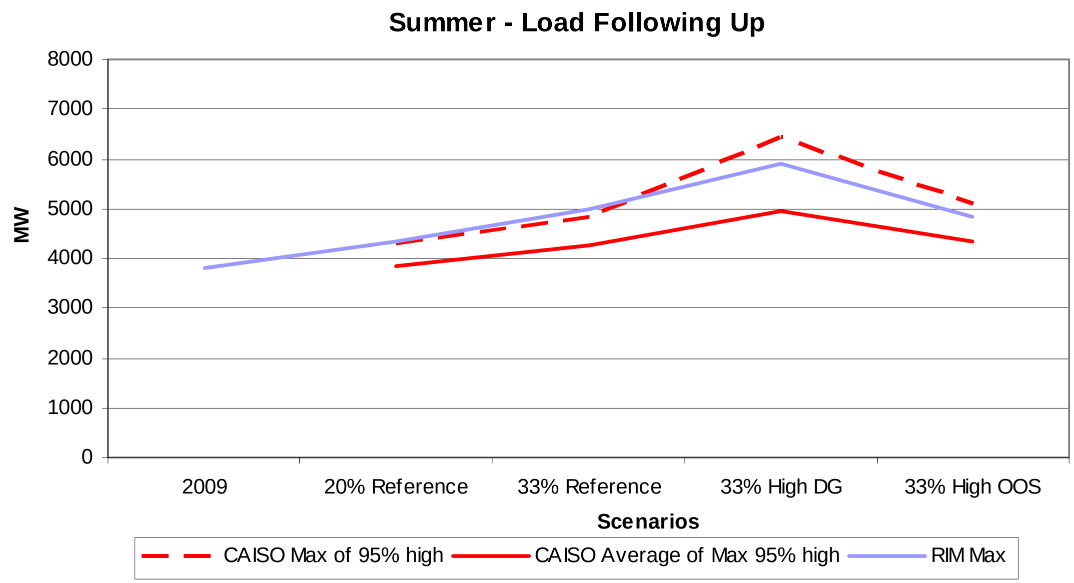
Operating Flexibility Requirements

		2009	20% Reference	33% Reference	33% High DG	33% High OOS
SPRING	REGULATION (MW)	406	477	713	1,117	566
	LOAD FOLLOWING (MW)	2,743	3,290	4,491	6,128	4,088
	DAY-AHEAD COMMITMENT (MW)	2,391	3,069	4,378	5,397	4,327
	Total	5,540	6,836	9,582	12,641	8,980
SUMMER	REGULATION (MW)	419	474	556	690	528
	LOAD FOLLOWING (MW)	3,819	4,334	5,001	5,920	4,832
	DAY-AHEAD COMMITMENT (MW)	2,857	3,338	3,803	3,877	4,036
	Total	7,095	8,147	9,360	10,488	9,395
FALL	REGULATION (MW)	405	466	623	906	532
	LOAD FOLLOWING (MW)	3,027	3,525	4,473	5,851	4,138
	DAY-AHEAD COMMITMENT (MW)	2,952	3,573	4,353	4,638	4,621
	Total	6,384	7,564	9,449	11,394	9,292
WINTER	REGULATION (MW)	412	470	640	957	525
	LOAD FOLLOWING (MW)	2,878	3,327	4,270	5,785	3,841
	DAY-AHEAD COMMITMENT (MW)	1,954	2,450	3,720	4,994	3,333
	Total	5,243	6,248	8,630	11,736	7,699

Comparison of regulation and load following requirements*

- CAISO's Step 1 estimates up and down services (average and maximum of hourly 95% high amounts shown)**
- RIM estimates regulation and load following amounts by season (seasonal maximum shown)
- RIM assumes up and down services are symmetrical





* See appendix for comparison of operational flexibility requirements in all seasons

** See CAISO's August 16, 2010 workshop material: Slide 75 for Summer load following-up, and Slide 81 for Summer regulation-up requirements.

Integration costs

User specifies integration cost inputs

- **Fixed Costs**
    - Fixed cost of resources in excess of reliability requirement, reduced by the profits of energy sold in the marketplace
- **Variable Costs**
    - Fuel and operating costs of resources providing flexibility services
- **Emission Costs**
    - Emission costs based on the incremental fuel use by resources providing integration services

In comparison, CAISO's approach (CAISO, p. 123) estimates:

- **Fixed cost of integration as the capital cost of generic resources required for integration**
- **Variable cost of integration is the difference between: (a) the production cost savings, and (b) the energy credit of intermittent generation**

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Outline

- RIM Objectives
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Demo

Run 27.5% RPS Scenario as sensitivity to 33% Ref

Inputs:

- Use 2020 Load and load forecast errors and variability
- Enter 27.5% RPS installed capacity for intermittent resources
- Use renewable forecast errors and variability from the 33% RPS scenario
- Use other inputs from 33% RPS scenario

		2020 RPS Scenarios	
		33% Ref. RPS	27.5% RPS
1. 2020 Installed MWs			
	Wind - Existing	3,244	3,244
	Wind - New	8,338	5,977
	PV	4,910	4,609
	Solar Thermal (CST)	6,968	5,323
	Total	23,460	19,153
2. Operating Flexibility Requirements, MW			
Spring	Regulation	713	
	Load Following	4,491	
	Day-ahead commitment	4,378	
	Total	9,582	
Summer	Regulation	556	
	Load Following	5,001	
	Day-ahead commitment	3,803	
	Total	9,360	
Fall	Regulation	623	
	Load Following	4,473	
	Day-ahead commitment	4,353	
	Total	9,449	
Winter	Regulation	640	
	Load Following	4,270	
	Day-ahead commitment	3,720	
	Total	8,630	

Demo

Run 27.5% RPS Scenario as sensitivity to 33% Ref

"Step 1" Output for 27.5% RPS:

- Operating flexibility requirements decrease by 6% to 14%, less in Summer than in other seasons, compared to the 33% Ref. RPS scenario.

		2020 RPS Scenarios	
		33% Ref. RPS	27.5% RPS
1. 2020 Installed MWs			
	Wind - Existing	3,244	3,244
	Wind - New	8,338	5,977
	PV	4,910	4,609
	Solar Thermal (CST)	6,968	5,323
	Total	23,460	19,153
2. Operating Flexibility Requirements, MW			
Spring	Regulation	713	634
	Load Following	4,491	3,985
	Day-ahead commitment	4,378	3,761
	Total	9,582	8,380
Summer	Regulation	556	520
	Load Following	5,001	4,690
	Day-ahead commitment	3,803	3,503
	Total	9,360	8,713
Fall	Regulation	623	566
	Load Following	4,473	4,066
	Day-ahead commitment	4,353	3,886
	Total	9,449	8,518
Winter	Regulation	640	582
	Load Following	4,270	3,893
	Day-ahead commitment	3,720	3,222
	Total	8,630	7,697

Outline

- RIM Objectives
- Review RIM Methodology/Inputs
- Preliminary Results
- Model Demonstration
- **Closing Thoughts**

Closing thoughts

- Possible uses of RIM in 2010 LTPP
  - Build resource portfolios for different load and RPS scenarios
  - Estimate integration costs for scenario metrics
  - Determine sensitivity of integration requirements and costs from different RPS scenarios and other changes in assumptions quickly
- Additionally, RIM gives users the opportunity to learn and improve their understanding about integration
- Prototype model is available under a licensing agreement with PG&E

Question and Answer

Additional Questions and Model Distribution

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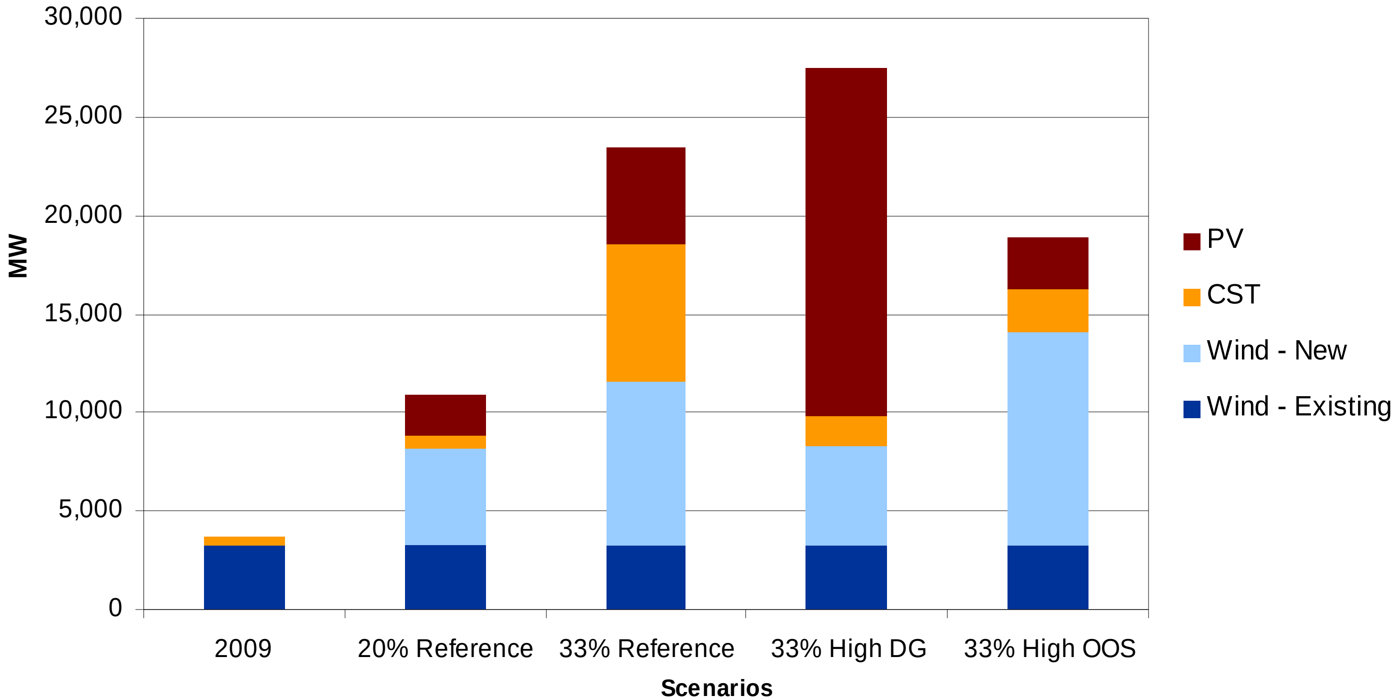
Appendix

Appendix
Renewable Resources for Scenarios

Four 2020 RPS scenarios

1.	**20% Reference Case**	blended renewable portfolio
2.	**33% Reference Case**	blended renewable portfolio
3.	**33% High DG Case**	high penetration of PV Distributed Generation (DG)
4.	**33% High OOS Case**	high Out Of State (OOS) imports, primarily wind

Intermittent Renewable Generation Scenarios



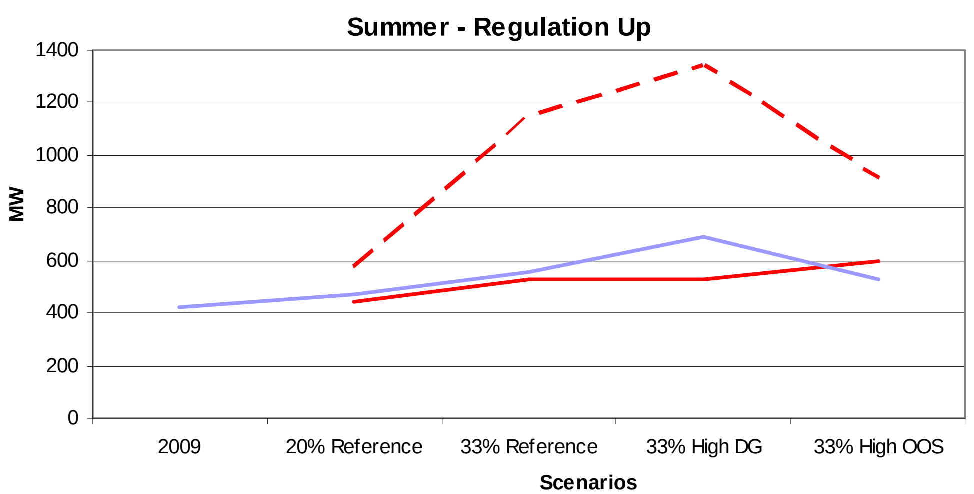
All scenarios include additional self-gen PV treated as PV supply to capture the integration requirement

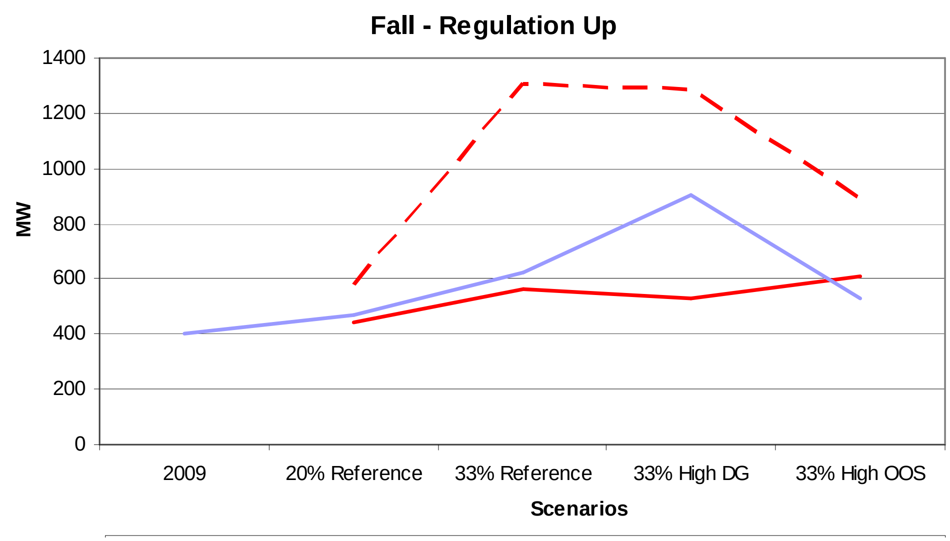
Appendix

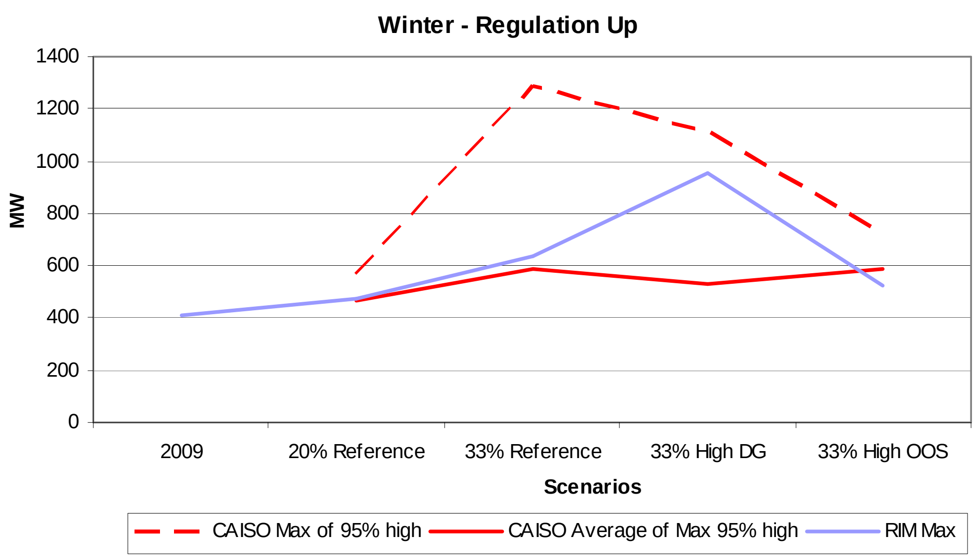
Forecast errors and variability

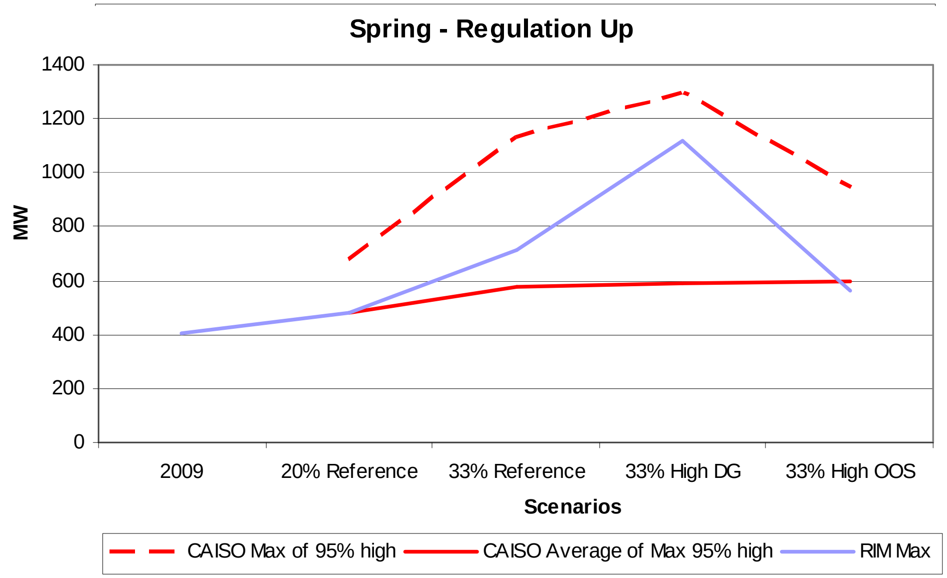
	Season	5-min Forecast Error	INTRA 5-min Volatility	HA Forecast Error	INTRA-Hour Volatility	Day-ahead Forecast Error
				2020 Load (Standard deviation errors and variability expressed in MW)		
CAISO	Spring	126		831		
	Summer	126		1,151		
	Fall	126		835		
	Winter	126		873		
RIM	Spring	138	55	823	472	1,000
	Summer	138	65	1,232	618	1,155
	Fall	138	56	941	512	1,354
	Winter	138	62	873	519	607
				Wind (Standard deviation errors and variability expressed as % of installed capacity)		
CAISO	Spring			5.0%		
	Summer			4.5%		
	Fall			4.4%		
	Winter			4.1%		
RIM	Spring	1.0%	0.2%	9.0%	1.3%	10.2%
	Summer	0.8%	0.2%	8.0%	1.1%	6.0%
	Fall	0.8%	0.3%	8.0%	1.0%	10.4%
	Winter	0.7%	0.2%	7.0%	0.9%	7.1%
	Clearness index (CI)			**Solar Thermal and PV** (Standard deviation errors and variability expressed as % of installed capacity)		
CAISO	0<=CI<=0.20			5.0%		
	0.2<CI<=0.5			10.0%		
	0.5<CI<=0.8			7.5%		
	0.8<CI<=1			5.0%		
RIM	Spring	1.6%	1.0%	5.6%	7.8%	8.7%
	Summer	0.7%	0.6%	4.1%	6.3%	2.5%
	Fall	1.2%	0.8%	4.7%	7.4%	5.5%
	Winter	1.3%	0.8%	5.4%	6.9%	8.3%

Regulation-up requirements comparison

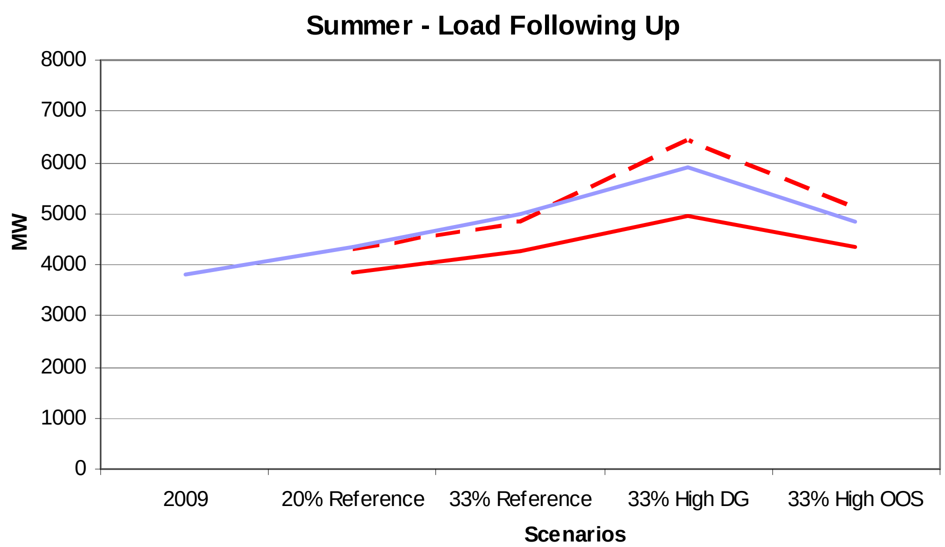


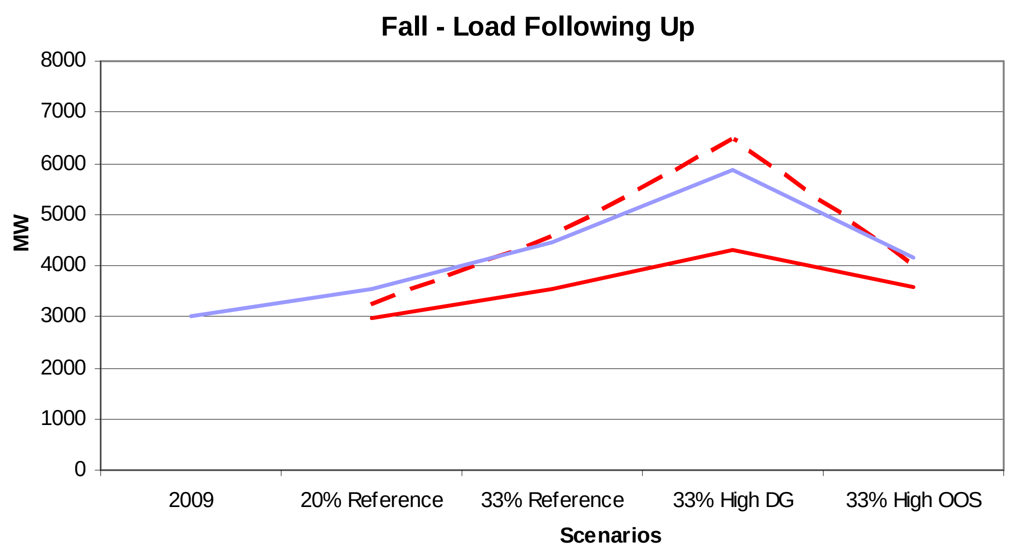


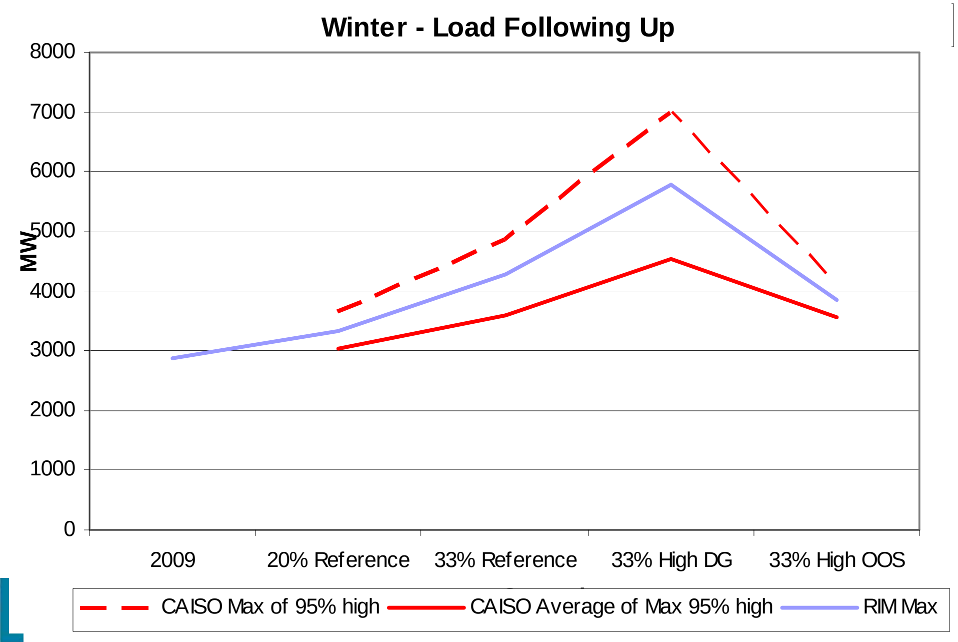


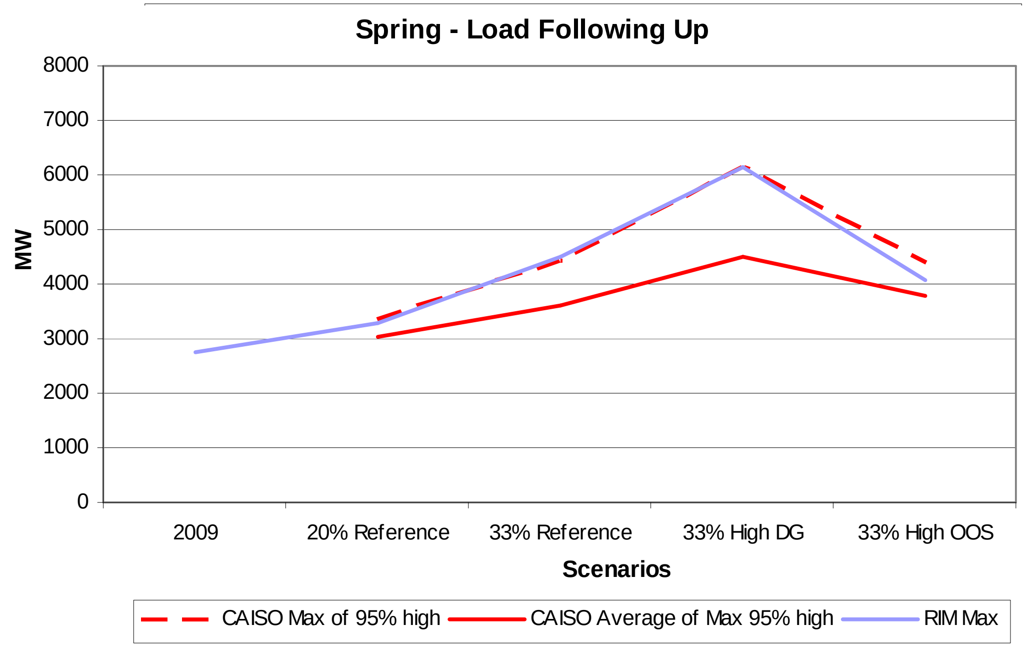


Load Following-up requirements comparison









New terms used in this presentation

- Day-ahead commitment requirement: resources that are required to be committed more than one-hour ahead to cover the additional forecast error of load and generation beyond that of hour-ahead forecasts or schedules.